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# Estimating spawning stock biomass in 2J3KL cod using a cohort maturation model and variable sex ratio

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Abstract

Estimates of proportion mature at age and age at 50% maturity were produced for Div. 2J3KL cod using a cohort maturation model. For 2J3KL combined, age at 50% maturity has been declining for both males and females since the earliest cohorts that could be estimated (those of the late 1950's). Differences between estimates of maturity from this method and the annual method are generally small but variable. SSB produced using the two methods show similar trends with a maximum difference of 246 000 t and 26%. Estimates of proportion female at age were found to increase with age and were variable across time. Comparison of SSB using fixed and variable proportions female showed that the two methods produced similar trends with the variable sex ratio method generally producing higher estimates with a maximum difference of 31 000 t or 9%. When SSB produced using annual estimates of maturity and a fixed sex ratio was compared to SSB produced using cohort estimates of maturity and a variable sex ratio the maximum difference was 95 000 t and 27%.

Résumé

La proportion de l'âge à maturité et de l'âge à 50 % de maturité a été estimée chez la morue 2J3KL à l'aide d'un modèle de maturation de cohorte. Pour l'ensemble des morues 2J3KL, l'âge à 50 % de maturité a diminué chez les mâles et les femelles par rapport aux premières cohortes estimées (fin des années 1950). Les différences entre les estimations de l'âge à maturité obtenues par cette méthode et les estimations obtenues par la méthode d'estimations annuelles sont dans l'ensemble petites, mais variables. La biomasse du stock reproducteur produite évaluée au moyen des deux méthodes montre des tendances similaires, avec une différence maximale de 246 000 tonnes et de 26 %. Selon les estimations, la proportion de femelles selon l'âge augmentait avec l'âge et variait en fonction du temps. La comparaison de la biomasse du stock reproducteur, obtenue en utilisant des proportions fixes et variables de femelles, a montré qu'avec les deux méthodes, les tendances étaient similaires; avec la méthode du sex-ratio variable, les estimations produites étaient en général plus élevées, avec une différence maximale de 31 000 tonnes ou de 9 %. La comparaison entre la biomasse du stock reproducteur produite obtenue à partir des estimations annuelles de la maturité avec un sex-ratio fixe et la biomasse du stock reproducteur produite obtenue à partir des estimations de maturité des cohortes et d'un sex-ratio variable montre une différence maximale de 95 000 tonnes et de 27 %.

## Introduction

Estimates of spawning stock biomass (SSB) from sequential population analyses are usually calculated by applying female maturity at age estimated on an annual basis to total biomass. This method makes the assumption that estimating maturities on an annual basis will accurately reflect the maturation of cohorts. This is not always the case as there are frequent occurrences where the proportion mature at age $a+1$ in year $y+1$ is less than at age $a$ in year $y$ (for example see Table 42 in Lilly et al., 1998). Such inversion means that fish that were adults last year are juveniles this year or that there is differential mortality on mature and immature fish.

This current method makes the further assumption that the sex ratio is 50:50 or at least invariant over time. For cod there tends to be an increase in the proportion female with age/size (Marshall et al. 1998; Jakobsen and Ajiad, 1999). More importantly there is evidence that the sex ratio can vary over time (Marshall et al. 1998). This variability in sex ratio will introduce an inconsistent bias in estimates of SSB.

The purpose of this paper is: to produce estimates of maturity at age for 2J3KL cod using a cohort maturation model; to compare these results to estimates of maturity on an annual basis; to compare estimates of SSB from these two methods; to explore variability in sex ratio across age and time; and to compare estimates of SSB using estimated and invariant sex ratio.

## Materials and Methods

Maturity data were collected during research vessel surveys from 1960-1999. Stratified random surveys were used from 1978-1999. Data from earlier years came from surveys that were conducted mainly as line transects. The coverage of the stock area would generally not be as complete as the stratified random surveys. Fish were classed as juvenile or adult based on the method of visual examination of gonads devised by Templeman *et al.* (1978) for haddock (*Melanogrammus aeglefinus*) and since applied to most groundfish species in the area. The first stage in this classification is immature (juvenile) and all other stages show some evidence of maturing to spawn or of having spawned in the past and are classed as mature (adult). For the period of the stratified random surveys, proportions mature at age were calculated according to the method described in Morgan and Hoenig (1997) to correct for bias introduced by length-stratified sampling. Prior to this, only data from the aged fish was used without weighting by the length frequencies. This should not have a large impact on the model estimates (Morgan and Hoenig 1997).

Maturities were modelled by cohort using the following generalized linear model with a logit link function and binomial error (McCullagh and Nelder, 1983; SAS Inst. Inc., 1993):

$$pmat = \log\left(\frac{u}{1-u}\right)$$

where: $pmat$= proportion mature at age or length

$$u = \tau + \delta_j v_i + \beta_j$$

$\tau$ = intercept
$v_i$ = age $i$
$\delta_j$ = combined age*cohort effect for cohort $j$
$\beta_j$ = cohort effect

Before a cohort was included in the model it was first tested separately to ensure that there was sufficient data to which to fit a model. Only cohorts with both a significant slope and intercept were included in the overall model. From this model, estimates of proportion mature at age as well as age at 50% maturity ($A_{50}$), were produced for males and females for Div. 2J, 3K, 3L and 2J3KL combined.

Estimates of maturity at age from the cohort maturation model were compared to annual estimates (Lilly et al., 2000). Both sets of estimates were used in conjunction with population numbers at age and weights at age from an SPA in Shelton and Lilly (In Press) to produce estimates of SSB. Since the estimates of maturity were from the fall for fish that would not be spawning until the next spawning season 1 was added to both the year and the age.

The proportion female at age was calculated from estimates of population numbers at age by sex from stratified analysis programs applied to fall research vessel data from 1978-1999. Proportion female was examined for trend across age and for ages 2 to 13 for trend across time. Estimates were smoothed using a lowess smoother. The smoothed estimates for ages 2 to 13 from 1979 to 2000 were used as the proportion female for that time period. Estimates of proportion female for ages 2 to 13 for all available years combined were smoothed across age to produce new estimates of proportion female at age to use prior to 1979 when annual estimates were not available. A new metric of SSB was produced as follows:

$$SSB = \sum_{a=2}^{13} N_a Pf_a Pm_a W_a$$

$N_a$= population numbers at age
$Pf_a$= proportion female at age
$Pm_a$= proportion females that are mature at age
$W_a$= mean weight at age

These estimates of SSB were compared to estimates where the proportion female was assumed to be 0.5 at all ages in all years. In both cases the estimates of maturity at age were produced using the cohort maturation model.

Finally estimates of SSB using annual maturities and an invariant sex ratio of 0.5 were compared to estimates produced using cohort maturities and the estimates of proportion female described above.

Results and Discussion

For 2J3KL combined, age at 50% maturity has been declining for both males and females since the earliest cohorts that could be estimated (those of the late 1950's, Fig. 1). Cohorts of the late 1950's had an average $A_{50}$ of 6.6 years for females and 5.7 years for males. Cohorts in the 1990's have had an average $A_{50}$ of 5.2 years for females and 4.0 years for males. This is a decline of 1.4 years or 21% for females and 1.7 years or 30% for males. Estimates on an annual basis have also indicated a decline of more than a year in $A_{50}$ for 2J3KL females (Lilly et. al. 2000).

When the divisions are examined separately, a similar degree of decline is seen (Fig. 2). $A_{50}$ declined in all 3 divisions but for females the decline was more variable in Div. 3L than in the other 2 divisions. $A_{50}$ tended to be highest in Div. 3L for both males and females. Maturity at an older age in Div. 3L was also found by Morgan et al (1994) with estimates produced on an annual basis.

Comparisons of estimates of maturity at age from the cohort maturation model with estimates produced annually are shown in Figures 3-5. The largest differences are in the early part of the time series. For the portion of the time series prior to 1982 there are no annual estimates, but rather the estimates for 1982 have been used in the calculation of SSB for the pre 1982 time period (Lilly et al., 1998). The cohort maturation model produces estimates for this early time period because of the extended data and because once a cohort effect is modelled, estimates can be produced for all ages of a cohort even outside of the range of the data. For the time period for which there are actual estimates from both methods the differences tend to be small but variable. A similar result was found by Morgan and Shelton (1995) using a slightly different cohort maturation model.

SSB estimates from the two methods show similar trends over the time period (Fig. 6). Prior to 1982 differences could be substantial, as high as 246 000 t and 26.5%. From 1982 on estimates using the annual method are available for each year and difference in SSB tended to be much smaller (maximum of 30 000 t and 8%).

Proportion female increased with age (Fig. 7). The smoothed estimates ranged from 0.43 to 0.53. Increased proportion female with age/size has also been shown for Northeast Arctic cod (Marshall et. al., 1998; Jakobsen and Ajiad, 1999). There was also considerable variability across the time period when the data is examined by age (Fig. 8). Ages 6 to 10 show an increase in proportion female from 1979 to 2000. These ages make up, on average, 82% of the SSB. It would appear that the assumption of a constant sex ratio is not correct. When SSB calculated using the variable sex ratio are compared to those calculated assuming a constant sex ratio of 0.5 the trends are similar (Fig. 9). The maximum difference was 31 000 t and 9%. The variable sex ratio generally produced a higher SSB.

Figure 10 shows the 'combined' difference of using cohort maturities and variable sex ratio. This compares estimates of SSB using annual maturity at age estimates and a constant 0.5 proportion female with SSB using cohort maturation estimates of maturity at age and a

variable sex ratio. Again the trend is similar for the two methods. The maximum difference is 95 000 t and 27%. Since 1982 the maximum difference was 19 000 t and 14%.

Differences in estimates of maturity at age produced using the two methods are generally small. However the cohort maturation model allows the estimation of maturities for an extended time period and is less affected by years with no data. Sex ratio is not constant across age or time but the difference in SSB tends to be relatively small. The combined effect of using estimates of maturity at age from the cohort maturation model and variable sex ratio can be substantial (14%) even during the period when annual estimates of maturity are available.

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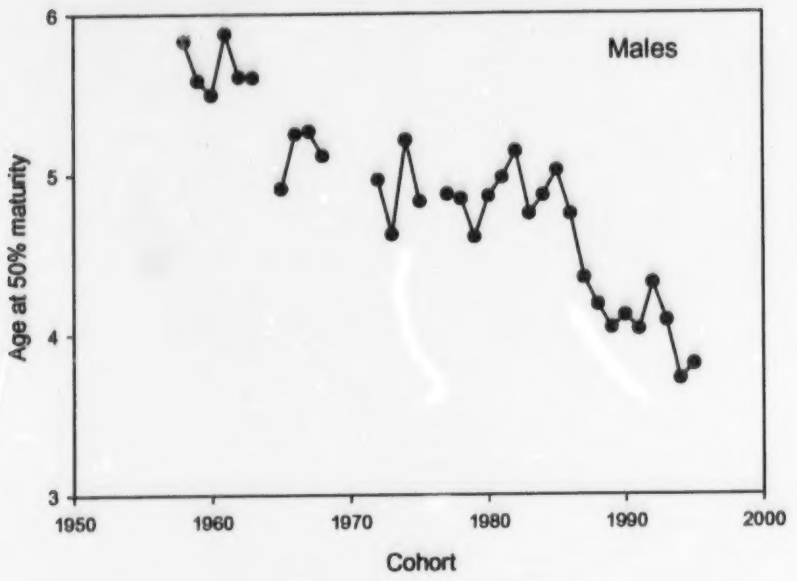


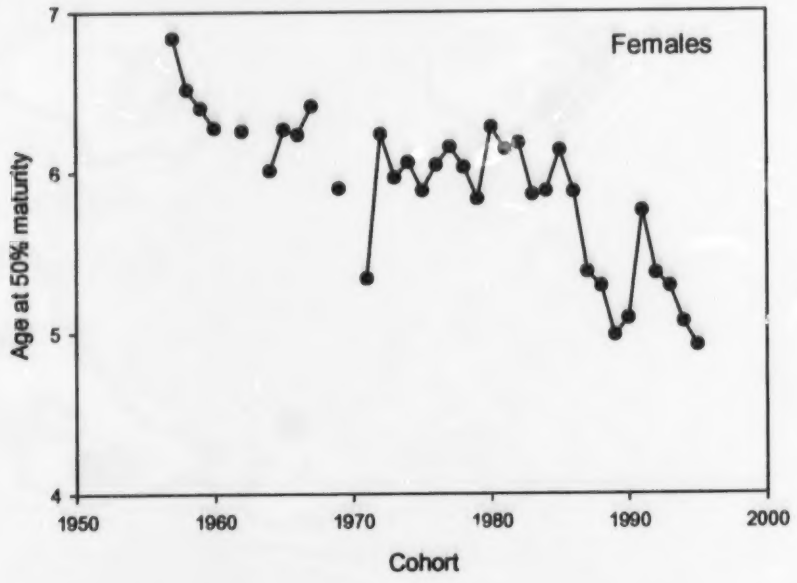


Figure 1. Age at 50% maturity for male and female 2J3KL cod as estimated from the cohort maturation model.

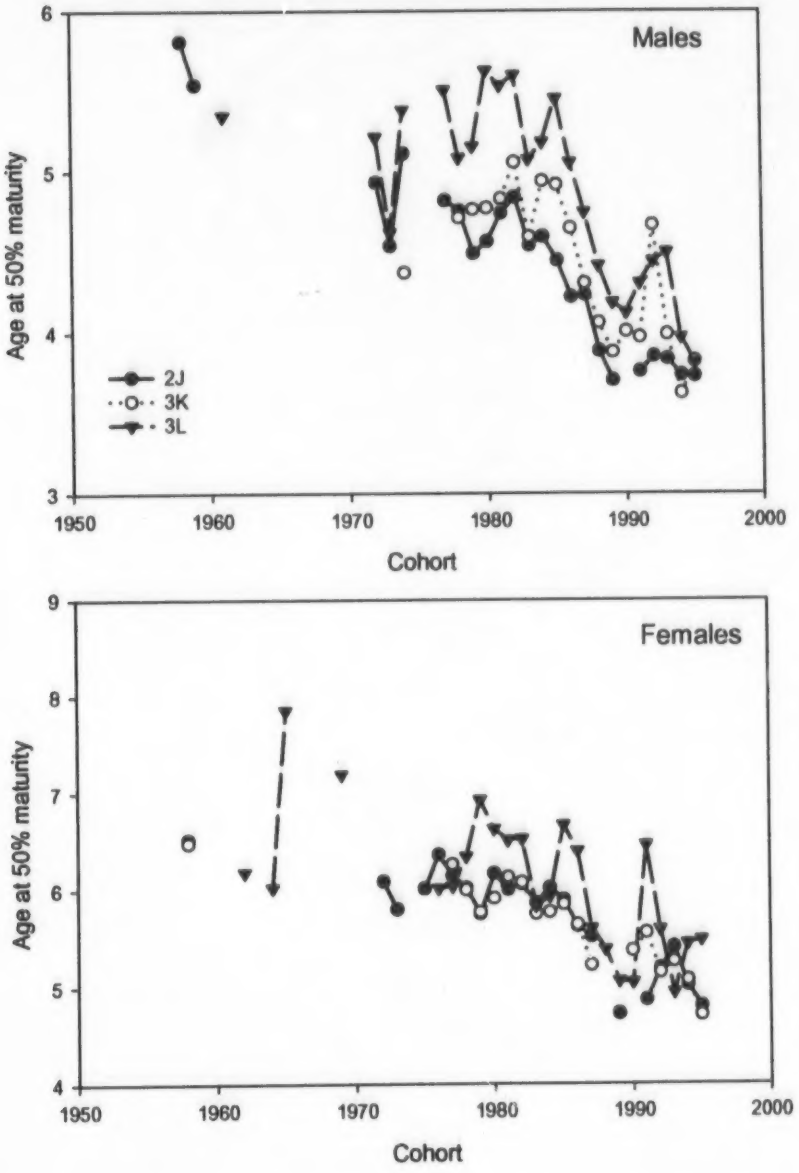


Figure 2. Age at 50% maturity for male and female cod from Div. 2J, 3K and 3L as estimated from the cohort maturation model.

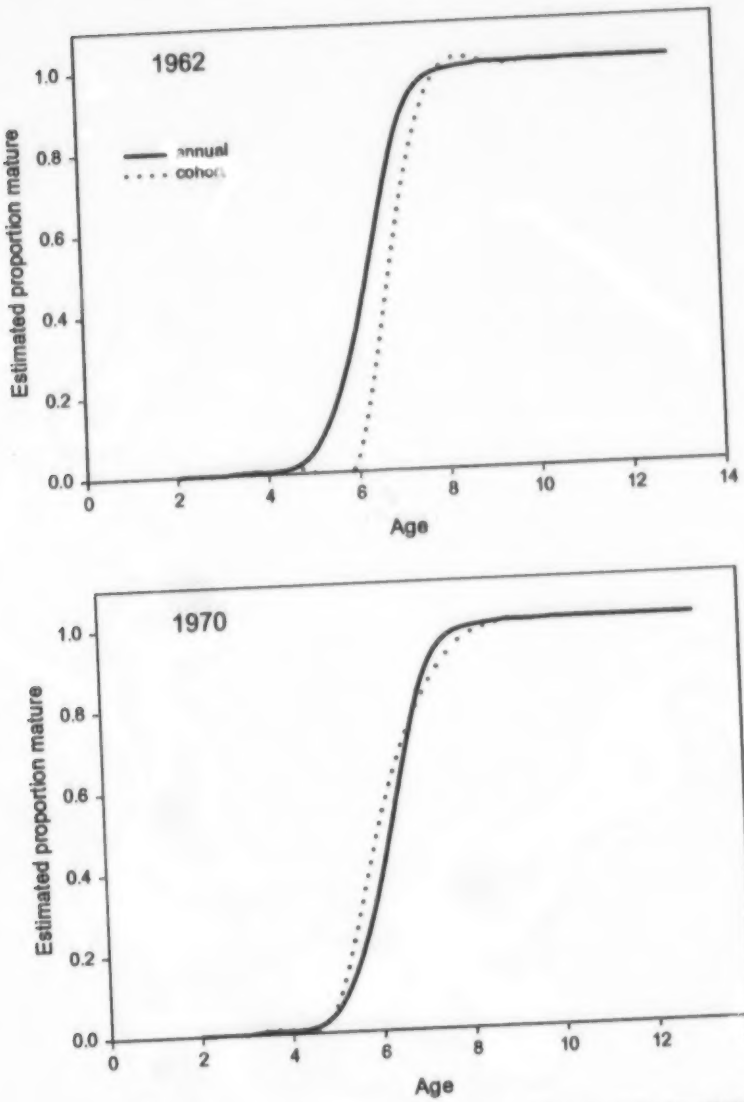


Figure 3. Estimates of female proportion mature at age for 2 selected years as used in calculations of SSB. Estimates are from the annual and cohort methods. The annual estimates are for the earliest year available (1982), the cohort estimates are from the years specified.

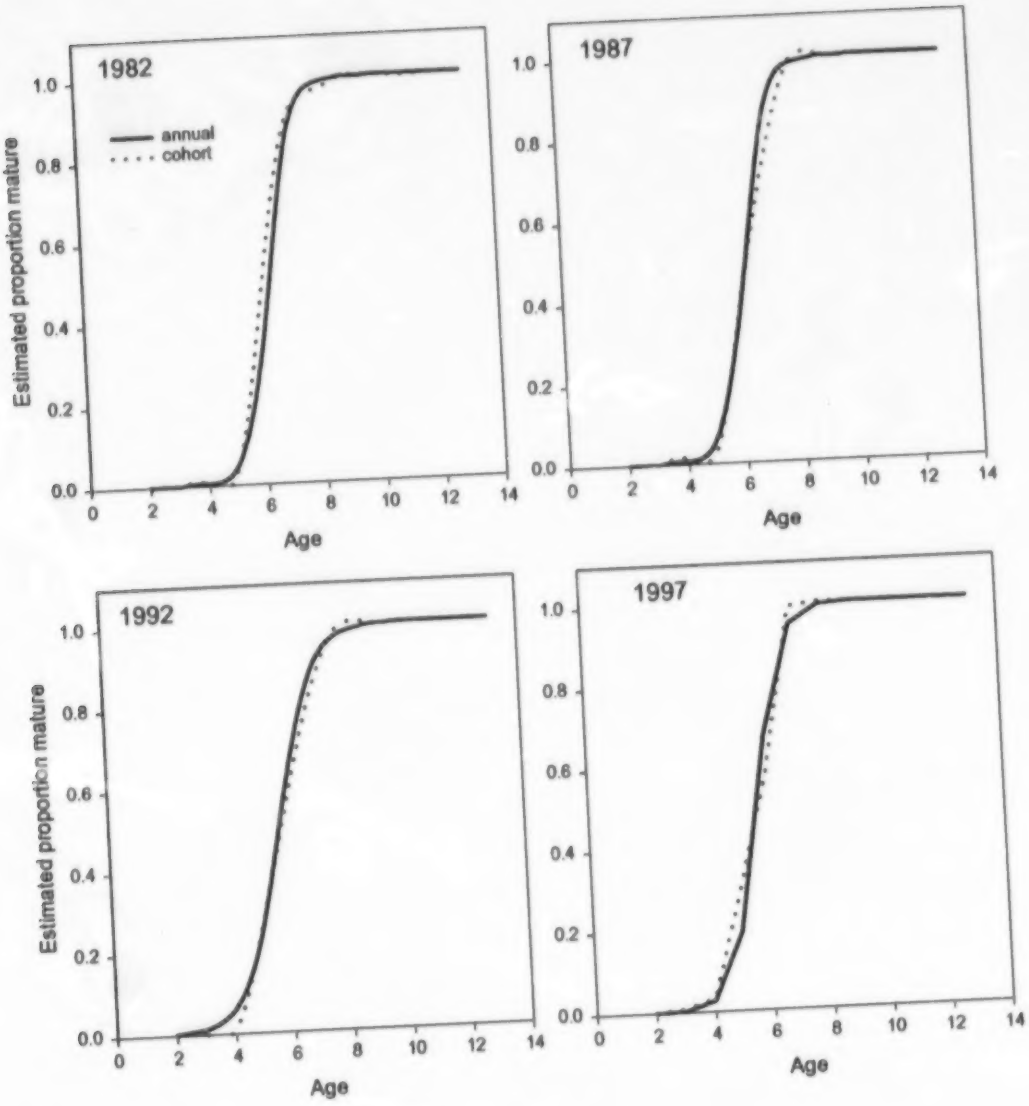


Figure 4. Estimated proportion mature at age of females for four selected years using the annual and cohort methods. These years have estimates from both models.

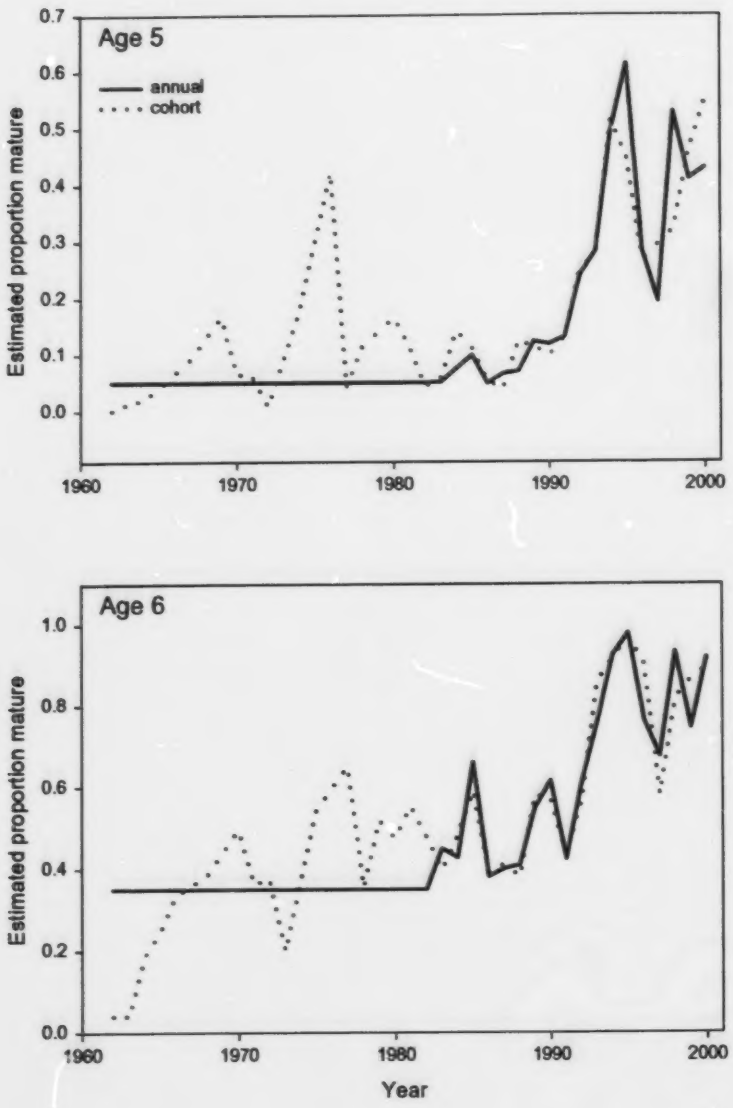


Figure 5. Estimated proportion mature of females aged 5 and 6 using the annual and cohort methods.

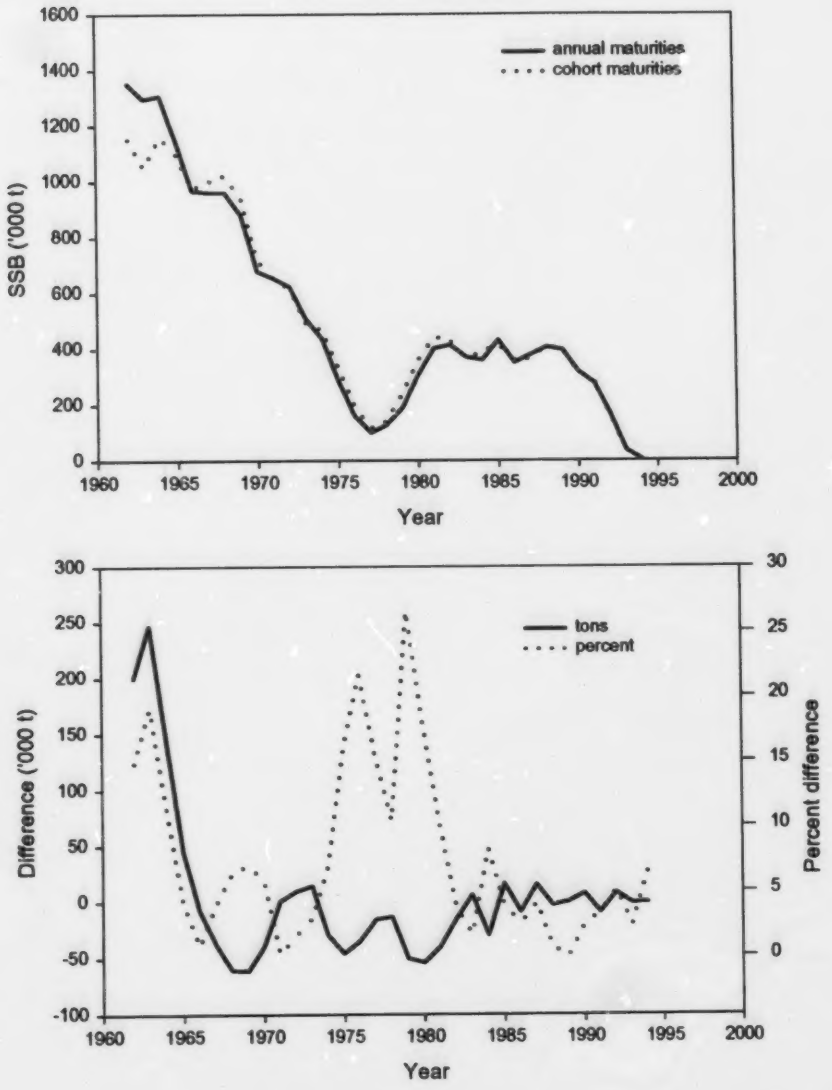


Figure 6. SSB calculated using annual and cohort estimates of maturity (top). The bottom panel shows the difference between these estimates (annual - cohort) and the percentage difference.

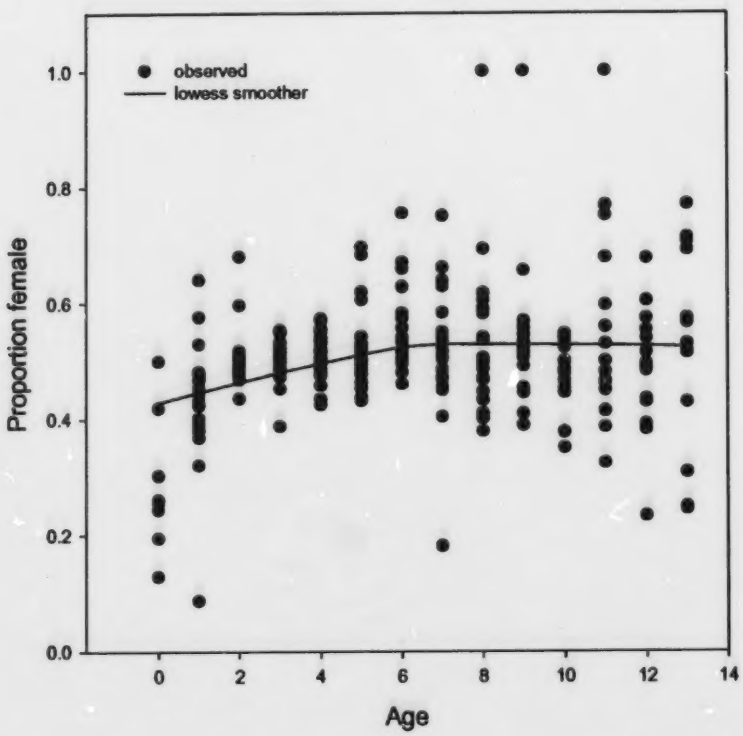


Figure 7. Proportion female at age as estimated from fall research vessel data. Observed and smoothed values are shown.

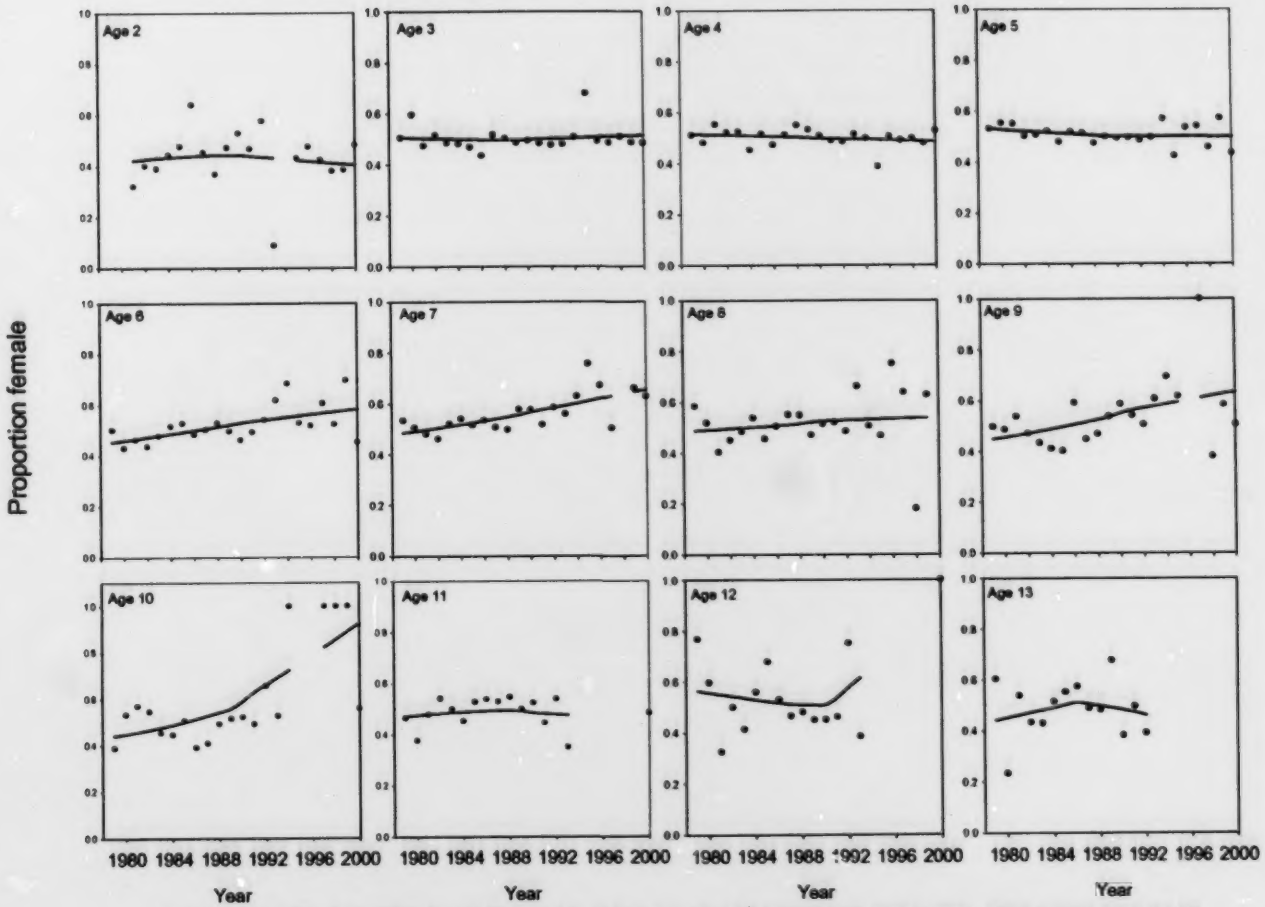


Figure 8. Estimates of proportion female for ages 2 to 13 from Canadian fall surveys from 1978 to 2000. Since surveys are in the fall one is added to the year and the age.

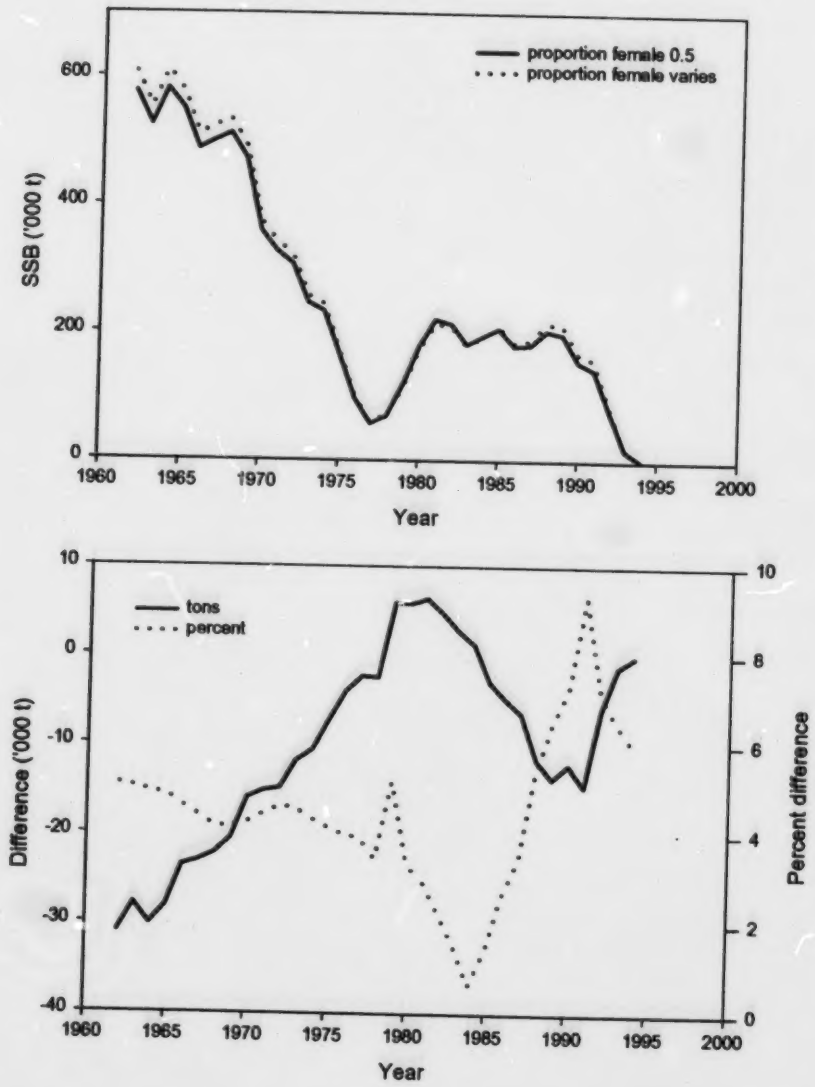


Figure 9. SSB calculated using constant and variable estimates of percent female (top). The bottom panel shows the difference between these estimates (constant 0.5 sex ratio - variable sex ratio) and the percentage difference.

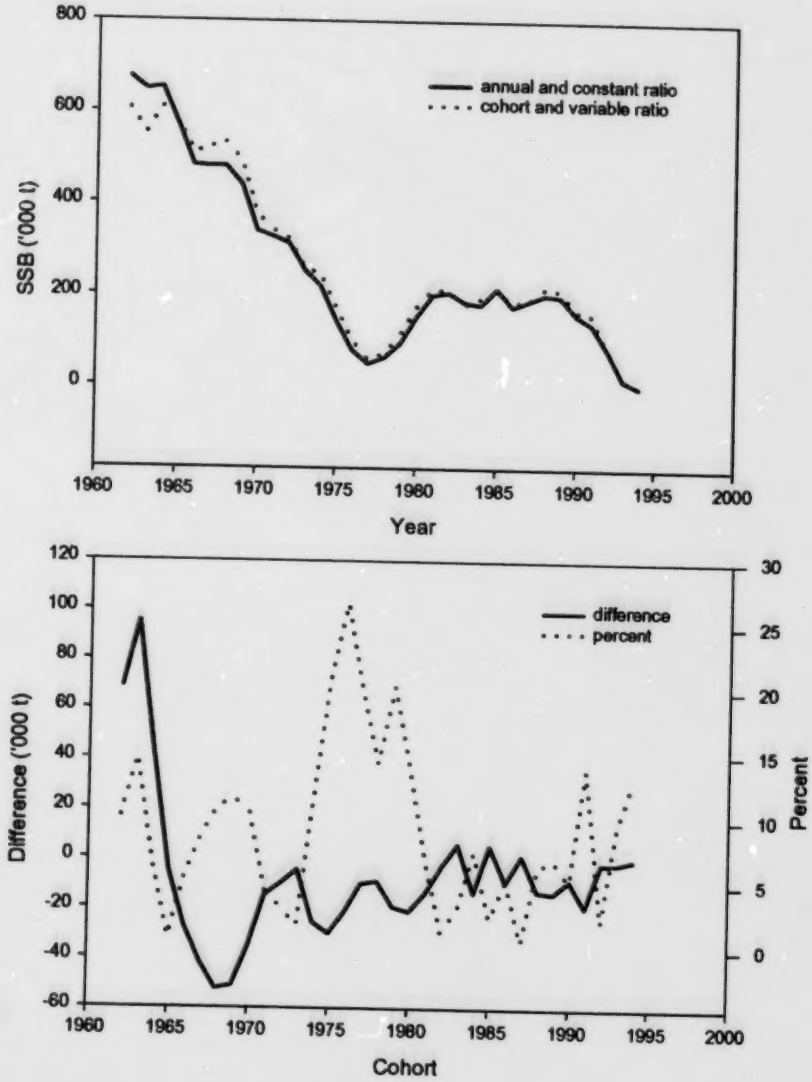


Figure 10. SSB calculated using constant sex ratio and annual estimates of maturity and using variable sex ratio and cohort estimates of maturity (top). The bottom panel shows the difference between these estimates ('000 t annual/constant - cohort/variable) and the percentage difference.